Ocean Acoustics Turbulence Study

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LONG-TERM GOALS

Measure the three-dimensional wave number spectrum of ocean turbulence using high frequency broadband acoustic scatter.

Quantify the acoustic scatter that results from medium variability while other sources of scattering commonly found in the ocean are present.

OBJECTIVES

The acoustic scatter from a region of medium variability can arise from scalar and vector sources. The scalar component can be the result of more than one fundamental property of the medium, i.e., sound speed or density. The objective of this work is to separate and quantify the scalar sources using high frequency broadband multi-static acoustic scatter; through which the temperature and salinity spectral variances can be determined.

APPROACH

Application of far field weak scattering theory to high frequency acoustic scattering from medium variability results in a technique that can be applied to multiple scalar source term extraction. The technique is the result of the far field Bragg scattering condition applied to broadband multi-static acoustic scatter and ending with a Newton's method algorithm utilizing the common Bragg wave number comparisons.

More specifically, sound will scatter whenever it encounters a discontinuity in the acoustic impedance, the product of sound speed and density. The general wave equation describing the acoustic scatter from medium variability is expressed in terms of the relative compressibility and density of the anomalous region. These sources of scattering are related to the relative temperature and salinity of the scattering region. Thus the acoustic scatter from medium variability in the ocean contains information relating to both thermal and saline variances. Because density has a much stronger dependence upon salinity than upon temperature and because density is a dipole scatterer, it suggests that multi-static acoustic scatter measurements can be used to exploit the explicit angular dependence of density in order to separate the spectral thermal and saline content of the medium variability.

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It has been shown that far field weak scattering theory accurately describes the behavior of the acoustic scatter from medium variability provided that wave front curvature measured over the scattering volume is negligible.[1] In the present case, the behavior of the acoustic source-receiver transducers used is well modeled by a baffled piston. Because of this, in order to recover the predictions of the far field approximation, it is required that the scattering volume be located in a transition zone between the first near field null referenced to infinity and the classical far field region. Following this, the Bragg scattering condition can be applied to multi-static measurements.

The Bragg wave number is essentially the scattering wave number; the magnitude is given by $K = 2k\,sin(\theta/2)$ and is called the Bragg scattering condition. The acoustic wave number of the incident pulse is given by k, and θ is the scattering angle measured from the forward direction. The equation for the complex acoustic scatter from medium variability arising from fluctuations in temperature and salinity, is given by $p_s(\omega) = \frac{kp_i(\omega)5.4l_w}{4\pi a}(a_T\tilde{T}(K) + a_S\tilde{S}(K))$, where p_i is the incident acoustic field, l_w is the width of the scattering volume in the plane of the incident and scattered wave vectors and perpendicular to the Bragg wave vector, a is the transducer radius, $a_T = 2\alpha + \beta(1-cos\theta)$, where $\alpha = 2e-3\ {}^oC^{-1}$, $\beta = -2e-4\ {}^oC^{-1}$, $\tilde{T}$ is the one-component three-dimensional Fourier transform of the temperature difference field, $a_S = 2\chi + \delta(1-cos\theta)$, where $\chi = 8e-4\ psu^{-1}$ and $\delta = 8e-4\ psu^{-1}$ and $\tilde{S}$ is the one-component three-dimensional Fourier transform of the salinity difference field. It is useful to rearrange the above equation and define a new wave number spectral quantity Φ as: $\Phi(K) \equiv \frac{4\pi ap_S}{kp_i 5.4l_w} = a_T\tilde{T}(K) + a_S\tilde{S}(K)$. Note that $|\Phi|^2 = a_T^2T^2 + a_S^2S^2 + 2a_Ta_STS\cos\Delta\phi$ where $\Delta\phi = \phi_T - \phi_S$. Thus, a three channel multi-static measurement made at the same Bragg wave number results in a system of three nonlinear equations with three unknowns. For the case of a turbulent saline-thermal plume the phase difference between the temperature and salinity variations equals zero, $\Delta\phi \equiv 0$. This is because the temperature and salinity are limited to the same regions of variability. The resulting over-determined three by two system of equations is solved using Newton's method. This root finding method iterates over a gradient field until the solution converges, i.e., the matrix solution $\Delta = -G^{-1}F$ where the elements of Δ are updated as $x_i^{new} = x_i^{old} + \delta_i$. For the current problem, the matrix G and vector F are expressed as:

$$[G] = -\begin{pmatrix} 2a_{T1}^2T - 2a_{T1}a_{S1}S & 2a_{S1}^2S - 2a_{T1}a_{S1}T \\ 2a_{T2}^2T - 2a_{T2}a_{S2}S & 2a_{S2}^2S - 2a_{T2}a_{S2}T \\ 2a_{T3}^2T - 2a_{T3}a_{S3}S & 2a_{S3}^2S - 2a_{T3}a_{S3}T \end{pmatrix},\ (F) = \begin{pmatrix} |\Phi_1|^2 - a_{T1}^2T^2 - a_{S1}^2S^2 - 2a_{T1}a_{S1}TS \\ |\Phi_2|^2 - a_{T2}^2T^2 - a_{S2}^2S^2 - 2a_{T2}a_{S2}TS \\ |\Phi_3|^2 - a_{T3}^2T^2 - a_{S3}^2S^2 - 2a_{T3}a_{S3}TS \end{pmatrix}.$$

Singular Value Decomposition of the matrix G is used to solve for Δ where $G = U\Sigma V'$ and $\Delta = -V\begin{bmatrix} 1/\Sigma(1,1) & 0 & 0 \\ 0 & 1/\Sigma(2,2) & 0 \end{bmatrix}U'F$. The convergence of the matrix iteration determines the temperature and salinity difference spectra at a given Bragg wave number; this process is repeated over all the available Bragg wave numbers. The result is the acoustic estimate of the temperature and salinity spectra from the received acoustic scatter.

WORK COMPLETED

Measurements of high frequency broadband multi-static acoustic scatter are made from a gravity fed thermal-saline jet. Three pairs of source-receivers are mounted around a 50 cm diameter ring such that they have parallel Bragg wave number vectors. The scattering angles used are 80, 120 and 160 degrees measured from the forward direction. The measurement process is similar to that previously described elsewhere.[2] The exit diameter of the jet is 1.2 mm, nominal jet velocity is 80 cm/sec, the scattering plane results in an x/D value of 83, and the jet Reynolds number is 953. The temperature and salinity differences for the results shown in this report between the reservoir tank and the measurement tank are 3.3 degrees C and 0.3 psu, respectively.

RESULTS

The Bragg wave number comparisons are shown in the figure below. These wave number spectra are determined using the fluctuations of the acoustic scatter about the mean and then averaged in wave number space. The Newton's method solution utilizes a spectral fit through each of the three channels of data in order to evaluate the matrix inversion at the same Bragg wave numbers.

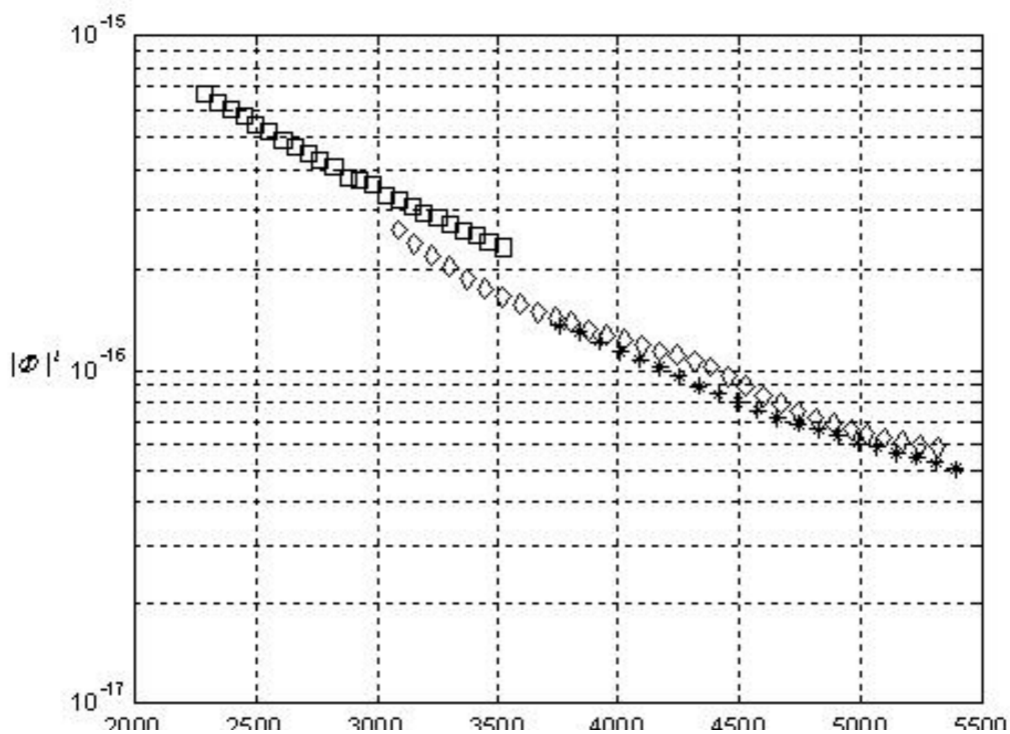

Figure 1. Squares, diamonds, and stars represent data collected at 80, 120, and 160 degree scattering angles.

The end result is shown in Fig. 2 where the wave number spectra of the temperature and salinity variances are illustrated.

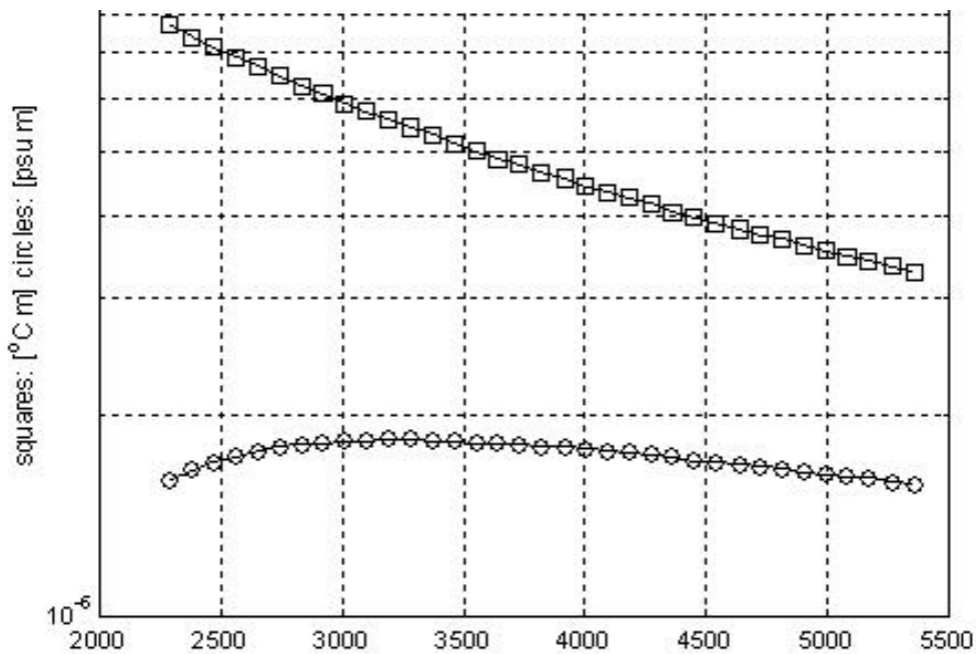

Figure 2. Temperature and salinity spectra obtained from multi-static acoustic scatter.

It should be noted that preliminary results reveal the expected systematic trends for the acoustically estimated temperature and salinity spectra. These include the corresponding relationship between the input temperature and salinity differences ratio to that determined acoustically, and that the temperature spectrum falls off faster with wave number than the salinity spectrum.

IMPACT/APPLICATIONS

This technique suggests that broadband high frequency multi-static acoustic scatter is capable of determining simultaneously temperature and salinity variances in the ocean.

TRANSITIONS

RELATED PROJECTS

REFERENCES

[1]Oeschger, J., Goodman, L., " Acoustic scattering from a thermally driven buoyant plume revisited," (to be submitted to JASA)

[2]Oeschger, J., Goodman, L., "Acoustic scattering from a thermally driven buoyant plume," J. Acoust. Soc. Am. , 100, 1451-1462 (1996)

PATENTS

Patent applied for under Navy Case 82547, Acoustic Scattering Measurement and Processing for Determining Variances in Multiple Features.